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EVALUATION OF BOND QUALITY AND CORROSION RESISTANCE OF STAINLESS STEEL-LOW CARBON STEEL FRICTION SURFACED DEPOSIT

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ABSTRACT

Friction surfacing is an advance surface modification process and it is solid phase welding technique by means of which similar and dissimilar metals easily be deposited one over the other effectively. This process preferable to get some special properties for the surfaced deposits of mechanical properties such as, shear strength or tensile strength, chemical resistance, wear resistance, corrosion resistance and electrical properties. In this study, details of the variants of friction surfacing techniques, the weldability of the stainless steel with the low carbon steel, selection of process parameters to get the desired properties, a deposit of corrosion resistance, mechanical testing of deposits and industrial applications are discussed in detail. By designing 2^3 experiments, the optimum parameters required for obtaining the desired responses of properties of bond strength, such as tensile strength and shear strength, surface roughness, width and height were determined. Also discussed are the effects of the parameters on the properties. The results of the corrosion test are discussed with applications like chemical pumps, pressure vessels and joining of dissimilar metals. Friction welding process has been commercialized in view of its importance and applications in defense, aerospace, electrical, automobile and many other industrial sectors.

KEYWORDS: Interface Properties, Weldability of Stainless Steel & Corrosion Resistance

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Original Article

INTRODUCTION

Low carbon steel has many applications in various fields due to its easy availability and good weldabiility in getting desired shapes. These components have need of protection from corrosion and wear. Surface properties of these components can be modified by coating with alloying, hard anodizing, electroplating and physical vapor deposition. By means of coating, desired material surface characteristics can be improved. However, they may fail when subjected to dynamic loads on account of mechanical bonding. Corrosion resistance is also a very important factor for increasing the life of the device. To solve these problems, the metals such as stainless steel, HSS, Tool steel, Inconel, intermetallics, MMC [1-5] and aluminum can be deposited on the surface of the low carbon steel by friction surfacing. Friction surfacing has gained a unique place in welding technology. Friction surfacing is the solid phase bonding process used in depositing the desired material over the substrate making use of frictional heat. This is a useful process for joining similar and dissimilar metals processing [6-9]. Friction surfacing is useful to face

challenging industrial problems**.** In friction surfacing process, the consumable is in the form of a solid bar called mechtrode it is rotated at a fixed speed advancing it under axial load on to the stationary plate called substrate. Frictional heat is developed at the interface between faying surfaces. The moving parts are subjected to dry friction during initial contact. After the rubbing action for a few cycles, there is a macroscopic local seizure and subsequent rupture by plastic deformation. This leads to a third body layer of finite thickness over the surface of the substrate. Then the substrate is moved with a fixed feed rate for achieving the desired thickness of the deposit on to the substrate material. The presence of high contact stress between substrate and mechatrode removes oxide films on the substrate surface. The process is to a large extent self-regulating. The deposit is free of porosity, cracks, slag inclusions or dilution associated with traditional welding processes [10-12]. The principle involved in friction surfacing is shown in Figure 1

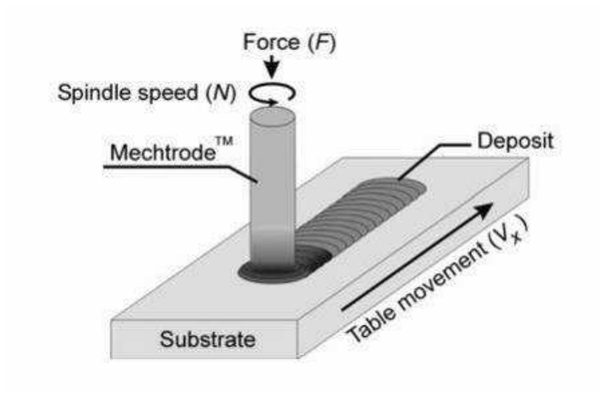


Figure 1: Principle Involved in Friction Surfacing

Friction pressure (Mpa), the rotational speed of consumable rod (rpm), transverse/welding speed of substrate material (mm/s) are the important process parameters by means of which the desired quality of the deposit can be achieved. Multilayer friction surfacing process is mostly suitable for cladding applications [13-14].

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials and Sizes for Experimental Work

The stainless steel consumable of 15mm diameter and 280 mm length and substrate with the size of the 10 X 85 X 450 mm is used. The microstructure tests of base materials are conducted according to standard IS 7739 and mechanical properties of base materials used for friction surfacing are shown in Table 1 and 2 respectively.

Table 1: Shows the Composition and Properties of base Materials

Materials	Fe	C	Mn	Si	S	P	Ni	Cr
Low carbon steel	99.4	0.2	<1.0	-	0.05	<0.05	_	_
Stainless steel (AISI 304)	66.2 to 70.2	0.08	2.00	1.0	0.03	0.045	8.0 to 10.5	18.0 to 20.0

Table 2: Shows the Mechanical Properties of Base Materials

Hardness (VHN)	Tensile strength (Mpa)	Yield strength (Mpa)	% of Elongation
172	558	428	21.6
261	615	318	62.03

Universal Testing Machine of 40 Ton is used for conducting mechanical tests of the specimens shown in figures 2 and 3. The consumables and substrate were cleaned and degreased with alcohol before friction surfacing.

Figure 2: Low Carbon Steel (substrate) Tensile Specimen

Figure 3: Stainless Steel (Mechtrode) Tensile Specimen

Equipment used for Friction Surfacing

The friction surfacing machine is of research type and deposition of stainless steel was carried out over low carbon steel. It has a 30 KW capacity and rotational speeds can be set in the range 1000-2400rpm with permissible axial force 9KN. The machine is capable of holding maximum 15 mm diameter of the consumable and the table size is 330 X 450mm provided with T slots for holding a substrate firmly.

Experimental Work

Statistical design of experimental approach [5-17] is ideally suited to minimize the number of trials required to optimize welding conditions. The three important parameters selected for the experimentation with 23 designs are Friction pressure (Mpa), the Rotational speed of the mechatrode (rpm) and Transverse speed of the substrate (mm/sec) in friction surfacing. Experimental design matrix indicating the eight treatment combinations is given in table 2. Using these eight treatment combinations, experiments were completed according to table 2 and test plates were made for the investigation [18-24]. Figure 4 shows some of the examples of deposits of Stainless steel over the low carbon steel.

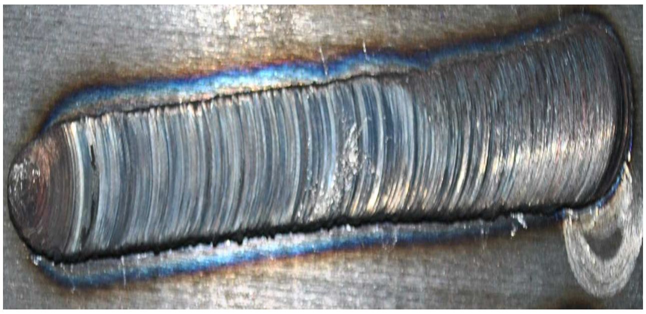


Figure 4: Deposition of the Stainless Steel over the Low Carbon Steel

Table 2: Process Parameters used for Stainless Steel Mechtrode and Low Carbon Steel Substrate

Treatment Combinations	Process Parameters		
	Friction Pressure (Mpa)	Rotational Speed of Mechtorde (rpm)	Traverse Speed of Substrate (mm/min)
1	29	1500	78
2	47	1500	78
3	29	2400	78
4	47	2400	78
5	29	1500	190
6	47	1500	190
7	29	2400	190
8	47	2400	190

TESTING

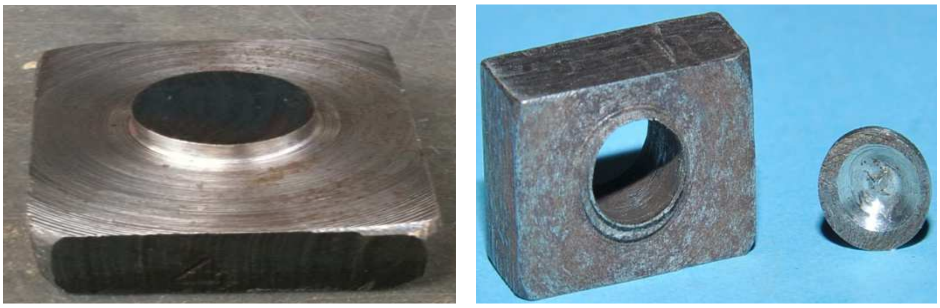
NDT techniques were used for evaluation of the quality of friction surfaced deposits**.** Initially, the visual inspection was performed for voids, pores and surface cracks. Adhesion strength was estimated primarily by performing lifting test, impact test, grinding wheel test, chisel and hammer test [25-26].

Measurement of Responses

Average physical responses like width, height and surface roughness of each deposit are measured. Shear strength as per the ASTM 264 and ram tensile test with 40 Ton UTM machine are performed on each deposit to find the bond strength of each deposit. All the values are tabulated in table 3. The specimen used for shear and tensile strength are shown in figure 5 and 6.

Speciment before Test **Specimen after Test**

Figure 5: Specimen before Shear Strength



Specimen before Shear Strength **Specimen after Tensile Strength**

Figure 6: Specimen after ram Tensile Strength

Table 4: Average Responses of each Deposit (Such as Height, Surface Roughness, Shear Strength and Tensile Strength)

TC	1 Width (mm)	2 Height (mm)	3 Surface roughness (u)	4 Shear strength (Mpa)	5 Tensile strength (Mpa)
1	11.2	1.56	6.86	74.0	313.5
2	12.7	2.71	2.84	82.6	430.9
3	11.81	1.41	6.05	75.5	664.8
4	14.18	1.72	1.74	161.2	467.8
5	10.43	1.04	6.10	161.2	519.3
6	12.35	1.11	7.73	181.6	484.1
7	10.68	0.81	6.75	168.3	307.9
8	13.24	1.42	9.68	362.2	377.7

Regression Equations

The generalized regression equation for 2^3 design of experiment [6] is given as $Y= Y_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_{12}X_1\ X_2 + \beta_{13}X_1\ X_3 + \beta_{23}X_2\ X_3 + \beta_{123}X_1\ X_2X_3$. The coefficients of the regression equations are calculated by ANOVA table. The test of significance was done and the final equations are shown in table 6 for various responses obtained after testing.

Table 6: Regression of each Response such as Width, Height, Surface Roughness Shear Strength and Tensile Strength of Deposit

S. No	Response	Average	Standard Deviation	Regression Equation
1.	Width	12.07	1.3	$Y= 12.07 + 1.04X_1 +0.4X_2 + 0.19X_1\ X_2 -0.4X_3$
2	Height	1.47	0.562	$Y= 1.47 + 0.27\ X_1 - 0.4\ X_3 -0.1\ X_1\ X_3$
3	Surface Roughness	5.97	2.57	$Y= 5.97 -0.47\ X_1 + 1.6X3 + 1.61\ X_1\ X_3 + 0.53\ X_2\ X_3$
4	Shear Strength	158.4	9.41	$Y= 15.84 + 3.86\ X_1 + 3.34X2 + 3.13\ X_1\ X_2 + 1.5\ X_1\ X_3 + 6\ X_3$
5	Tensile Strength	445.8	11.75	$Y= 44.58 -2.6\ X_1X2 -2.4X3 + 1.4\ X_1X3 -8.8\ X_2\ X_3 + 5.2\ X_1\ X_2\ X_3$

Bend Test

Root bend test, Face bend test and Side bend test are used in determining the soundness of the deposit, the deposit junction and the heat affected zone. Root bend test and Root bend tests are used primarily to determine the degree of weld penetration. Inside bend test, which is a severe test the deposit undergoes compression and expansion simultaneously.

Specimens are made as per the guidelines of ASTM E290, ISO 7438, and JIS Z2248 for bend testing for the ductility of metallic materials. Three samples are made to meet the requirements of the standard for performing the bend tests. Dye penetration tests is conducted to ensure that the specimens are free of cracks, or voids. Universal Testing Machine (UTM) of 40 Ton capacity is used for the bend test. The figure 7, shows one of the samples used for bend test, figure 8, the procedure for performing the test and the figure 9 and specimens used for the bend test.

Figure 7: Sample used for Bend Test

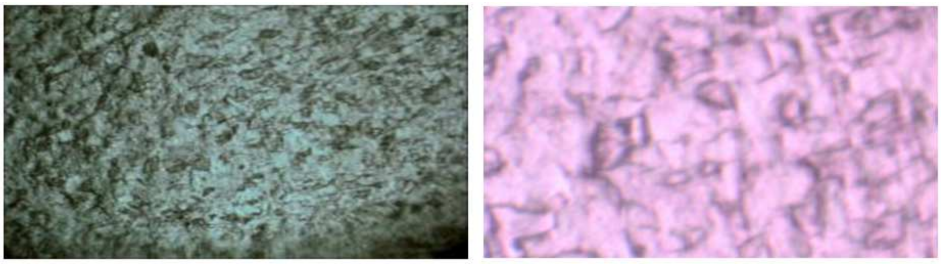
Figure 8: Jig and Mandrel used for Bend Test

Specimen After Face Bend Test Specimen After Root Bend Test Specimen After Side Bend Test

Figure 9: Specimen of Face, Side and Root Bend Tests

Corrosion Test

Corrosion test is carried out according to the standard ASTM A 262 by keeping the specimen at 650^0 C for one hour. After corrosion test, the microstructure shows in figure10.



Microstructure of Stainless Steel Before Corrosion Test Microstructure of Stainless Steel After Corrosion Test

X 100 Etchant: Aqua Regi X 100 Etchant: Oxalic acid

Figure 10: Specimen used for Corrosion Test

Micro Hardness

Microhardness survey is conducted across the interface of stainless deposit over the low carbon steel according to standard procedure IS 1501-2002 with the Vickers Hardness tester. The table shows the variation of hardness across the

interface of the deposit.

Table 7: Micro Hardness Survey of across the Friction Surfaced Deposit

Distance of the Point with Respect to Interface Layer	Longitudinal Direction (HV1)	Transverse Direction (HV1)
Towards stainless steel at 1.0 mm	189	219
Towards stainless steel at 0.8 mm	189	219
Towards stainless steel at 0.6 mm	185	214
Towards stainless steel at 0.4 mm	185	214
At the interface	129	127
Towards the low carbon steel at 0.4 mm	136	182
Towards the low carbon steel at 0.6 mm	148	182
Towards the low carbon steel at 0.8 mm	148	175
Towards the low carbon steel at 1.0 mm	153	168

RESULTS AND DISCUSSIONS

The specimens after face bend, root bend, and side bend tests are observed under a stereomicroscope and it was found that the deposit was not separated, torn or cracked on the deformed surfaces. Hence it is concluded that the plates which are coated with stainless steel over the low carbon by friction surfacing can be rolled, deformed or shaped to make the shells or containers for storage of corrosive fluids.

Radial drilling machine, milling machine or lathe machines can also be employed for the friction surfacing with special attachments. But Special purpose friction surfacing machine is suitable for control of process parameters.

At the initial stage of friction surfacing, the machine experiences large vibrations, as there is peak torque because of the presence of dry friction, decreases after few seconds and maintain equilibrium.

Selection of process parameters for friction surfacing of a given combination of materials plays a vital role in the protection of the special purpose machine and getting good bond strength.

The surface when observed carefully revealed that it is free of porosity cracks, blisters, pits, roughness, or undercut problems, which are generally encountered in fusion welding process as in some magnitude or other. These are also indicating, the friction surfacing process is the solid state welding.

The primary adhesion test showing that the deposit had sufficient bond and hence it concluded that the friction surfacing is one of the best metal joining processes, which can be used to surface the dissimilar metal combination conveniently. The dry penetration test is conducted for the deposit, it is found that the surfaces are free of defects such as cracks or voids or holes. It indicates that the obtained joint is perfect.

The width of the deposit change from start to equilibrium stage. The width of the deposit lies between 2/3 and 3/4 of its diameter and depends on the selection of process parameters. The width of the deposit is proportional to speed and axial force and inversely proportional to the transverse speed of the mechtrode.

The height of the deposit increases with the increase of axial force, and decreases with transverse speed of the substrate and so there is no effect of speed.

Surface roughness is also proportional to substrate transverse speed and its value decreases with the increase in axial pressure.

Shear strength increases on par with the three process parameters, but the tensile strength decreases with transverse speed.

The selection of process parameters mainly depends on the suitability of this process for applications. For corrosion resistance, the base material has to cover the entire area with considerable bond strength.

The specimens of bend tests are observed under a stereomicroscope and it was found that the deposit is not separated, torn or cracked on the deformed surfaces. The microstructure before and after corrosion test clearly indicates that there was no pitting. Hence this technique of surfacing of austenitic stainless steel over carbon steel can be recommended for critical corrosion resistant applications like layered vessels, chemical pumps and agricultural equipment.

The micro hardness test shows there is a little quantity of hardness decreased at the interface, when compared with the transverse direction to below the base metal value. This is due to energy concentration is at the center of the consumable, in friction surfacing process.

APPLICATIONS AND LIMITATIONS

Experimental results show that the friction surfacing could be used as a method for obtaining coatings of dissimilar materials.

Friction surfacing has potential application in industries due to improved reliability and productivity, suitable for batch production, reduction in cost, superior quality and the achievement of what was previously impossible. This process can also be attempted in the robotics for full automation.

Friction surfacing is the solid-state welding process and it is confirmed that the problems associated with fusion welding are eliminated. This method is suitable for repair and reclamation of worn and damaged parts. This process also can be performed underwater without a sealing mechanism.

This process can be performed in open air and not required any inert gases to prevent oxidation.

This process is most suitable for the consumables which are having a less thermal conductivity than the substrate and poor sliding characteristics. This evidence can be observed while doing friction surfacing with aluminum and copper mechtrodes which poses difficulties.

CONCLUSIONS

Friction surfacing is the best method for obtaining deposits stainless steel over low carbon steel for critical applications. Heat affected zone is comparatively less and very minimum distortion is expected. No shielding gas is required. Corrosion test and bend test results proved that this method can be applied for the manufacture of petrochemical vessels, pumps for chemicals and other corrosion resistant applications.

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